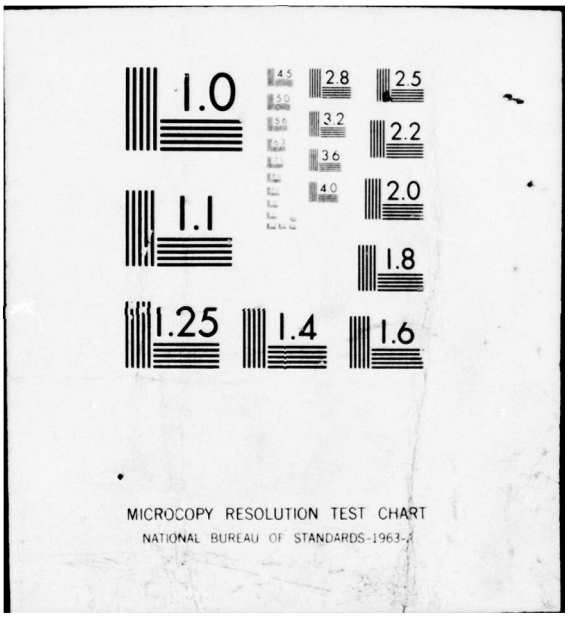
AD-A043 722 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/2
ARCADIA LAKE WATER-QUALITY REPORT STUDY. SUMMARY REPORT.(U)
JUL 77 R W HALL, R L ELEY, D L ROBEY

UNCLASSIFIED WES-MP-Y-77-3 NL

| OF |
AD
A043 722

END
DATE
FILMED
9-77
DDC


1.0
1.1
1.25
1.4
1.6
2.8
2.5
3.2
2.2
3.6
2.0
4.0
1.8
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MISCELLANEOUS PAPER Y-77-3

SUMMARY REPORT
ARCADIA LAKE WATER-QUALITY STUDY

by

R. W. Hall, Jr., R. L. Eley, and D. L. Robey

Environmental Effects Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

July 1977
Final Report

Prepared for U. S. Army Engineer District, Tulsa
P. O. Box 61, Tulsa, Okla. 74102

Destroy this report when no longer needed. Do not return it to the originator.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (14) WES-MP- Miscellaneous Paper Y-77-3	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE *(and Subtitle)* (6) SUMMARY REPORT, ARCADIA LAKE WATER-QUALITY REPORT STUDY	5. TYPE OF REPORT & PERIOD COVERED (9) Final report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) R. W. Hall, Jr., R. L. Eley, D. L. Robey	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Effects Laboratory U. S. Army Engineer Waterways Experiment Station P. O. Box 631, Vicksburg, Miss. 39180	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer District, Tulsa P. O. Box 61, Tulsa, Okla. 74102	12. REPORT DATE (11) July 1977 13. NUMBER OF PAGES ~~29~~ (12) 31 p.
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*	15. SECURITY CLASS. *(of this report)* Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Arcadia Lake, Okla.
Mathematical models
Nutrients
Water quality

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The water quality of the proposed Arcadia Lake, Oklahoma, was evaluated relative to water-quality criteria and standards appropriate for the project purposes. Study procedures included evaluation of existing data and previous studies of streams and lakes in the project area; collection and evaluation of additional field data; determination of available and limiting nutrients through algal bioassays; establishment of relationships between stream discharges and loadings of nutrients, metals, and pesticides based on stream concentrations and land-use patterns; application of various mathematical models; and comparison of predicted or measured results with existing or proposed water-quality criteria.

A comparison of average values for 70 water-quality parameters with the most stringent standard or criterion revealed that ammonia, manganese, mercury, DDT, dieldrin, aldrin, chlordane, lindane, heptachlor,

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

20. ABSTRACT (Continued).

PCB, phenols, and fecal coliforms equaled or exceeded permissible or recommended levels at least part of the time. Only coliform bacteria, ammonia, and manganese exceeded present Oklahoma standards applicable to proposed reservoir uses. Ammonia would not be expected to reach toxic concentrations in the hypolimnion of Arcadia Lake or interfere with project purposes.

Nutrient evaluations based on concentrations and loading indicated that the proposed impoundment would be eutrophic and that algal blooms were likely to occur during the late spring and summer months. Algal bioassays and ecological model simulations indicated that not all of the available nutrients would be used because of light limitation. Algal blooms are expected to minimally interfere with recreational purposes of the lake because surrounding nutrient-rich Oklahoma reservoirs presently receive heavy recreational use and alternative, less eutrophic recreational reservoirs do not exist in the project area. It would not be feasible through watershed management practices or reservoir operational strategies to reduce in-lake nutrient concentrations sufficiently to limit algal growth. Routine chemical treatments are not feasible nor compatible with all project purposes. A capability for selective withdrawal of municipal and industrial water supply releases would be of benefit in minimizing treatment costs.

Manganese concentrations and occasionally iron concentrations are expected to exceed drinking water standards in the hypolimnion and headwaters of the proposed impoundment. Iron and manganese would be less likely to exceed standards in the epilimnion near the dam. Excessive iron and manganese would not be a problem in finished water supplies if the potential problem is recognized in the design of the water treatment plant.

Average mercury concentration computed over all samples collected near Arcadia was ten times less than the public water supply criterion but exceeded the criterion for the protection of freshwater aquatic life. Results of analyses of the mercury content of fish collected in the Deep Fork River indicated body-burden concentrations less than Food and Drug Administration (FDA) and Environmental Protection Agency (EPA) limits.

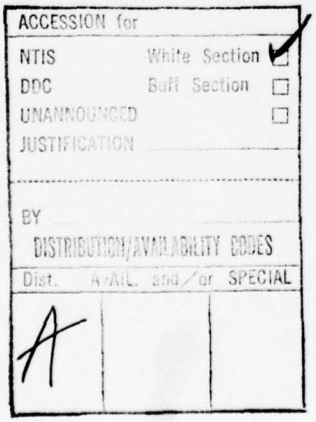
Pesticides would not be expected to be a water-quality problem in Arcadia Lake because sorption and precipitation would reduce concentrations significantly and restricted use of some of the pesticides has been implemented or is proposed by the EPA. Heptachlor epoxide concentrations in fish exceeded FDA administrative guidelines. However, the rare occurrence of heptachlor, the failure to detect heptachlor epoxide in Deep Fork River water samples, the failure to detect heptachlor or heptachlor epoxide in river sediments, and the fact that the EPA has banned the distribution and use of the pesticide suggest that heptachlor and its degradation products will not exceed criteria in the proposed impoundment. Detectable phenol concentrations would be expected to occur only in the headwaters because of rapid decay and dilution.

Coliform bacterial contamination would be limited to the headwaters of the proposed impoundment during base flow. Coliform bacteria might occasionally exceed standards in the lower portions of the pool, following major storm events in the watershed. But even then dilution probably would prevent concentrations from exceeding standards.

The impoundment would be expected to exhibit weak thermal stratification during the late spring and summer months. Wind-mixing would determine the degree of stratification. Downstream temperature objectives could be met by project releases if selective withdrawal were practiced. It is expected that dissolved oxygen of project releases will be approximately 80 to 90 precent saturation due to reaeration as flows pass through the outlet works and stilling basin.

If Arcadia Lake is constructed, water-quality data collection should continue through pre- and postimpoundment in order to provide a basis for lake management to meet intended project purposes.

THE CONTENTS OF THIS REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES. CITATION OF TRADE NAMES DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS



Preface

The work described in this report was performed by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, for the U. S. Army Engineer District, Tulsa. The project was authorized by Intra-Army Order for Reimbursable Services No. DOL 740015, dated 2 August 1974 and amended 31 August 1976.

This report provides a brief nontechnical summary of a water-quality study of the proposed Arcadia Lake. A technical report prepared by the WES entitled "Arcadia Lake Water-Quality Study" and a supplemental report entitled "Water-Quality Evaluation of a Lower Pool Elevation for Proposed Arcadia Lake, Oklahoma" provide detailed descriptions of the data and procedures used in this study (Technical Reports Y-77-2 and Y-77-3, respectively).

The study was accomplished by the Environmental Effects Laboratory (EEL) at WES. The research was conducted under the direct supervision of Dr. R. L. Eley, Chief, Ecosystem Research and Simulation Division, and Mr. D. L. Robey, Chief, Ecosystem Modeling Branch, and the general supervision of Dr. John Harrison, Chief, EEL. Mr. R. W. Hall, Jr., and Drs. K. W. Thornton, D. E. Ford, and R. H. Plump, Jr., served as principal investigators. Dr. A. S. Lessem and Messrs. B. Loftis and P. E. Saunders participated in the study.

Commander and Director of the WES during the preparation and p[illegible]ion of this report was COL J. L. Cannon, CE. Technical Director wa[illegible]. F. R. Brown.

Contents

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
acre-feet	43,560	cubic metres
square miles (U. S. statute)	2.58999×10^6	square metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) readings from Fahrenheit (F) readings, use the following equation: $C = (F - 32)/1.8$. To obtain Kelvin (K) from Fahrenheit, use: $K = (F + 459.67)/1.8$.

SUMMARY REPORT
ARCADIA LAKE WATER-QUALITY STUDY

Introduction

This report provides a brief nontechnical summary of a water-quality study of the proposed Arcadia Lake. The study was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) at the request of the Tulsa District, Corps of Engineers. A technical report prepared by the WES entitled "Arcadia Lake Water-Quality Study"* and a supplemental report entitled "Water-Quality Evaluation of a Lower Pool Elevation for Proposed Arcadia Lake, Oklahoma"** provide detailed descriptions of the data and procedures used in this study. These reports are available from the Tulsa District and should be consulted for additional technical information.

Background

The proposed Arcadia Lake would be formed by impoundment of the Deep Fork River in central Oklahoma east of Oklahoma City. The river originates in northwest Oklahoma City, flows 6 miles† through the metropolitan area, and then flows 10 miles through predominantly pastures and woodlands to the proposed damsite. The Arcadia Lake watershed covers an area of 105 square miles of which 39 percent is open land, 33 percent is urbanized, and the remaining 28 percent is wooded, pastured, or cultivated. At conservation pool elevation, the proposed impoundment would have a surface area of 1820 acres and a volume of 27,570 acre-ft. Average depth would be 15 ft and maximum depth at the structure would be 56 ft.

---

* Hall, R. W., Jr., et al., "Arcadia Lake Water-Quality Evaluation," Technical Report Y-77-2, April 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

** Thornton, Kent W., et al., "Water-Quality Evaluation of a Lower Pool Elevation for Proposed Arcadia Lake, Oklahoma," Technical Report Y-77-3, May 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

† A table for converting U. S. customary units to metric (SI) units is given on page 4.

The Arcadia Lake project as presently formulated would consist of a multiple-purpose lake for flood control, municipal and industrial water supply, and recreation. This type of project would satisfy the desires of local interests, who have expressed a primary need for water supply and water-oriented recreation.

Oklahoma State University (OSU) was contracted by the Tulsa District in 1972 to evaluate the existing water quality of the Deep Fork River and to predict expected water quality in Arcadia Lake. The OSU study was initiated in part to satisfy certain requirements of the National Environmental Policy Act of 1969 and to determine if expected water quality was acceptable for the project purposes of water supply and recreation.

The OSU study concluded that contaminant concentrations in the Deep Fork River often exceeded surface water criteria for public water supplies, that bacteriological counts exceeded recommended standards for primary contact recreational use, and that existing concentrations of nutrients might stimulate blooms of nuisance algae. Primarily on the basis of the OSU report, the U. S. Environmental Protection Agency (EPA) recommended that public and industrial water supply and recreation not be included as project purposes.

Although the OSU study provided a useful compilation of water-quality data collected in the upper Deep Fork River basin prior to 1972, the appraisal of the possible water quality of the proposed Arcadia Lake was inconclusive because the scope of the study was not sufficient to adequately evaluate the uncertainties associated with their predictions. The scope of the OSU study also did not allow for an adequate assessment of what the future water quality of the reservoir would be in comparison to the observed quality of the stream.

Perhaps of greater significance, Deep Fork River chemical data that served as the basis for the OSU appraisal were collected during a time in which the effluents of up to six sewage treatment plants and lagoons contributed over 28 percent of the average discharge measured near the proposed damsite. For many extended periods, sewage plant effluents constituted the only flow in the stream. During the same period, industry and many small businesses were discharging contaminants directly into the river or indirectly through storm sewer systems. The runoff of contaminants from

The watershed and the direct discharge of municipal and industrial wastes had degraded the water quality in the upper Deep Fork River for most beneficial uses.

Since publication of the OSU report, one sewage treatment plant was relocated outside the Arcadia watershed; a second plant relocation was planned; and operations of two sewage lagoons were discontinued. In addition, major industrial sources of contaminants were identified and their effluents diverted through existing sanitary sewer systems.

Because of the inconclusiveness of the OSU study and the profound changes that had occurred in the proposed Arcadia Lake watershed since publication of the OSU report, the Tulsa District contracted the WES to more thoroughly investigate possible water-quality problems identified in earlier studies. The WES investigations were to include consideration of recent and proposed changes in the watershed.

Study Approach

To provide reliable predictions, a number of approaches were used in this study to address the same basic questions. These procedures included:

a. Evaluation of existing data and previous studies of streams and lakes in the project area.

b. Collection and evaluation of additional field data.

c. Determination of available and limiting nutrients through algal bioassay procedures.

d. Establishment of relationships between stream discharges and amounts of nutrients and contaminants based on stream concentrations and land-use patterns.

e. Application of mathematical models.

f. Comparison of predicted or measured results with existing or proposed water-quality criteria.

Representatives from the Tulsa District and Southwestern Division Offices of the Corps, the Oklahoma State Department of Health, and the Dallas Regional Office of the EPA concurred with the study methodology during a meeting held in Dallas during October 1974, prior to initiation of the WES study.

Survey of Existing Data and Additional Studies

A major effort in the study was the evaluation of data previously collected by other agencies. This approach (a) provided information on the number and duration of past studies that could be used for predicting the water quality of the proposed Arcadia Lake; (b) indicated those water-quality parameters that had been measured and the frequency of the measurements, and provided an estimate of the magnitude and variation in the water quality that could be expected in the Deep Fork River; (c) permitted the identification of major sources of contamination in the watershed; and (d) indicated what additional data were needed to adequately predict water quality in the proposed impoundment.

Identification of Water-Quality Parameters Warranting Further Analysis

A survey of previous water-quality data for the Arcadia Lake watershed was undertaken to identify potentially toxic or harmful constituents for which criteria or standards exist. This evaluation of existing data for 70 water-quality constituents revealed that 25 water-quality parameters had at least one sample value equal to or exceeding one-tenth of the most stringent criterion or standard and 12 water-quality parameters had a mean value equal to or exceeding the most stringent criterion or standard.

The U. S. Geological Survey (USGS) data were used most extensively in the water-quality survey because these data were the most comprehensive; samples were collected at regular intervals; and corresponding river discharge data were also available. The USGS data provided estimates of over 70 water-quality parameters measured over a 5-yr period. Grab samples were collected at monthly intervals, while composite samples, on the average, were collected weekly. Extensive nutrient data and limited metal data collected within the Arcadia Lake watershed by the Oklahoma Water Resources Board, Oklahoma State Health Department, OSU, Oklahoma City-County Health Department, Water Pollution Control Division of the Department of Public Works, and Mr. Jimmie Pigg of Moore High School, Moore, Oklahoma, were within the ranges measured at the Arcadia damsite.

For purposes of the evaluation, toxic or harmful constituents found to exceed the most stringent criteria or standard at least once received further analysis. The nutrients nitrogen and phosphorus warranted additional evaluation since their presence in high concentrations is generally considered to result in nuisance algal blooms.

Major Sources of Contaminants

Water-quality data collected by the Oklahoma State Department of Health and the Oklahoma City Water Department indicated that the municipal effluents of Oklahoma City and Edmond are major point sources of contaminants to the upper Deep Fork River. A comparison of effluent discharges with measured loadings near Arcadia revealed that the Edmond Southeast and Oklahoma City Northside Sewage Treatment Plants (STP's) contribute over 90 percent of the phosphorus and approximately 75 percent of the nitrogen. Significantly, the Edmond Southeast STP was relocated outside the Arcadia Lake watershed in August 1974, and the Northside plant is scheduled to be removed from the watershed.

Prior to 1974, numerous small industries were discharging into storm sewers or directly into the upper Deep Fork River. However, major sources of industrial contaminants were identified by 1974, and their effluents redirected through sanitary sewer systems. Based upon industrial waste load allocations developed and promulgated by the Oklahoma State Department of Pollution Control, industrial point-source pollution appears insignificant relative to measured total loadings near Arcadia. This suggests that most of the present loadings come from sewage treatment plants and non-point-source stormwater runoff.

Additional Sampling Programs

Lakes Eufaula and Thunderbird

At the request of the WES, the USGS in coordination with the Tulsa District established a sampling program on two existing impoundments, Lakes Thunderbird and Eufaula, in order to observe directly the distribution of materials in the tributary stream, impoundment water column,

and bottom sediments. These sites were selected for study because they were considered to be two of the best existing analogs available to provide insight into relationships between the nature of inflows from the Deep Fork River and the water quality that might be expected in the proposed impoundment.

Northside Sewage Treatment Plant

The Northside STP is a major point source of contaminants in the proposed Arcadia Lake watershed. Because this source would be diverted below the proposed Arcadia Lake and very limited data on the quality of this effluent were available, the Tulsa District contracted OSU to sample nutrients, metals, pesticides, and other constituents in the final effluent of the sewage treatment plant. These data were used to estimate water-quality parameter concentrations that would be expected in the Deep Fork River following treatment plant relocation.

Algal bioassays

The WES conducted algal bioassay studies using established EPA methodologies to assess the availability of nitrogen and phosphorus compounds and the nutritional state of algae in the Deep Fork River system and surrounding waters. These studies were initiated because observed nutrient concentrations greatly exceeded levels that are generally accepted as adequate to support nuisance algal blooms. The purpose of the studies was to evaluate whether algal growth limitation would be expected to occur because nutrients in the Deep Fork River were in an unavailable form or because of limitation by factors other than nitrogen and/or phosphorus.

Mercury sampling

During the course of this study, data collected by the USGS indicated that mercury could be a potential problem. The paucity of existing data precluded reliable evaluation of the possible water quality of Arcadia Lake with respect to this constituent. In coordination with the WES, OSU conducted additional mercury sampling in the Deep Fork River near Arcadia to supplement the very limited USGS data.

The Tulsa District provided continuity in mercury sampling of the Deep Fork River by contracting the Oklahoma State Health Department to

conduct sampling of both the river and the final effluent of the Northside STP at weekly intervals during the period 29 March through 1 June 1976.

During a February 1976 meeting held in Dallas, representatives from the Dallas Regional Office of the EPA recommended that fish be collected from the Deep Fork River near the proposed damsite and analyzed for mercury content. The results of the analysis could be used directly to determine the suitability of the fish presently in the Deep Fork River as a food source by comparing body burden concentrations to U. S. Food and Drug Administration (FDA) limits and could be used to determine the existence of possible adverse environmental effects of mercury contamination by comparison to EPA criteria. Furthermore, the procedures of fish flesh analysis would provide adequate sensitivity, which is difficult to attain in the analysis of water samples. This study recommended by the EPA was expanded to include lead and all chlorinated pesticides that were considered possible problem parameters in the proposed impoundment. The rationale for these body burden analyses was that contaminant concentrations in the proposed reservoir, in some cases, should be lower, and in no case would be higher, than existing concentrations in the stream. Therefore, if fish presently living in the stream did not exceed established limits, fish living in the proposed reservoir would be expected to meet all environmental and health standards.

Bacteriological sampling

Prior to the initiation of this study, two total coliform bacteria and three fecal coliform bacteria sample values measured near Arcadia by the USGS were available. Although the values obtained are reasonable for urban drainage, additional studies were needed to more precisely estimate the magnitude and frequency distribution of coliform bacteria concentrations. The Tulsa District contracted the Oklahoma State Health Department to conduct total and fecal coliform analyses of water samples collected in the Deep Fork River near Arcadia and in the effluent of the Northside STP.

Results of WES Investigation

Temperature and dissolved oxygen

Mathematical modeling studies indicated that the impoundment would be generally well mixed because of shallow depths and strong prevailing winds. Ephemeral temperature stratification would occur during extended periods of calm weather. During intermittent periods of stratification of the impoundment, warmer waters overlying cooler waters would prevent the mixing of surface and bottom waters.

A selective withdrawal structure would be required for the proposed project for water-quality management purposes. Arcadia Lake release temperatures from a properly operated selective withdrawal structure would approximate the existing annual variation of stream temperatures adequately to satisfy environmental quality requirements. Release temperatures during the summer and fall months may be about 12°F warmer than average natural downstream temperatures.

The bottom waters occasionally would become devoid of dissolved oxygen during intermittent periods of stratification. However, dissolved oxygen concentrations in releases should be satisfactory because withdrawals could be made from the oxygenated surface waters and, in the case of bottom withdrawal, adequate reaeration would occur as the water passes through the outlet works into the stilling basin.

Nutrients and eutrophication potential

Eutrophication is a natural process of excess nutrient enrichment and excessive biological productivity. Eutrophic waters are characterized by nuisance levels of algae at least sometime during the year, anoxic bottom waters during periods of stratification, and other potential water-quality problems. In assessing the eutrophication potential of the proposed Arcadia Lake, emphasis was placed on nitrogen and phosphorus since the evidence is overwhelming that these are the major nutrients controlling algal productivity in water bodies and because Deep Fork River data indicate that carbon could not be a limiting nutrient. Excessive eutrophication would be expected when the rate of supply of required nutrients in available form is in excess of nutritional needs necessary

to maintain acceptable algal levels when other factors such as light availability, temperature, or toxic materials are not limiting algal growth.

Nutrients are abundant in the Deep Fork River. Although sewage treatment plant effluent diversion would greatly reduce phosphorus and nitrogen loadings, the resulting concentrations would greatly exceed levels normally considered to result in nuisance algal blooms.

The evaluation of nitrogen and phosphorus in the Deep Fork River based on concentrations and loading analyses suggests that the proposed impoundment would be eutrophic. Mathematical model simulations suggest that algal blooms would occur after impoundment. The magnitude of these blooms are expected to be similar to those occurring in Lakes Keystone, Thunderbird, and Carl Blackwell. However, algal response was relatively insensitive to variations in nitrogen and phosphorus loadings but responded noticeably to changes in light availability. These results suggest that despite sewage treatment plant diversions and any other reasonable efforts to reduce nutrient loadings, nutrients would be available in excess of algal needs and that algal growth would be limited by light availability. Bioassay results corroborate the hypothesis of light limitation by demonstrating that all the available nutrients in the Deep Fork River were not being used. Light availability in the reservoir will be determined by the degree of turbidity or suspended solids concentration in the surface waters. Even during periods of low turbidity, algal blooms will tend to be self-limiting at high concentrations by reducing light penetration and availability through self-shading.

The bioassay nutrient availability study also indicated lower available nutrient concentrations in Lake Eufaula relative to the Deep Fork tributary and in Lake Thunderbird relative to the Little River tributary. It can thus be anticipated that nutrient concentrations in the proposed impoundment would be lower than historical data for the Deep Fork River at Arcadia.

Other test results indicate that the relative abundance of nitrogen and phosphorus would be affected by impoundment of the Deep Fork River and sewage effluent diversion. At present nitrogen concentrations are

lowest relative to need at Arcadia, but phosphorus concentrations are lowest relative to need above the Northside STP.

Algae contribute to taste and odors and other problems such as high particulate concentration and variable water chemistry requiring treatment plant control measures. Excessive algal densities may be visually displeasing; while decomposition of massive algal accumulations may liberate obnoxious odors.

During periods of temperature stratification and algal blooms, water supply treatment costs could be increased. A capability for selective withdrawal of municipal and industrial water supply releases would be of benefit in minimizing treatment problems.

Algal blooms are expected to cause minimal interference with recreational purposes of the lake. Surrounding nutrient-rich Oklahoma reservoirs presently receive heavy recreational use and alternative, less eutrophic recreational reservoirs do not exist in the project area.

It would not be feasible, either through watershed management practices or reservoir operational strategies, to reduce in-lake nutrient concentrations sufficiently to limit algal growth. Furthermore, routine chemical treatments do not appear feasible or compatible with all project purposes. Future land-use changes are not expected to affect lake eutrophication since light rather than nutrients would limit algal growth.

Metals

The evaluation of trace metal data from the Deep Fork River involved a comparison of reported concentrations with recently recommended EPA water-quality criteria. EPA criteria were selected because Oklahoma's standards did not provide numerical limits for the metals of interest.

A comparison of average concentrations of 25 trace metals measured by the USGS in the Deep Fork River near Arcadia during the period of 1969-1974 with EPA criteria revealed that manganese and mercury exceeded the proposed limits. Average iron concentrations were near maximum permissible levels. These metals, which were found to approach or exceed numerical limits, received further study to assess their potential for water-quality degradation in the proposed impoundment. Lead data also were analyzed in more detail because previous studies reported excessive lead concentrations.

Iron and manganese. Iron and manganese are different from mercury and the other metals considered in this study in that the standards for iron and manganese are based on aesthetic considerations and other metal standards are based on toxicity. Excessive iron and manganese in water supplies can cause "red water" and "black water," respectively, that will result in unsightly stainings.

Manganese concentrations are expected to frequently exceed drinking water standards in the headwaters and in the bottom waters of the lower portion of the proposed impoundment. Iron is expected to occasionally exceed standards in the same waters. Increases in both iron and manganese concentrations in the bottom waters would coincide with ephemeral periods of temperature stratification and the depletion of oxygen in the bottom waters. Strong prevailing winds are expected to completely mix the water column of the proposed impoundment most of the time, resulting in well-oxygenated bottom waters. In well-oxygenated waters, most of the iron and manganese will be associated with the sediments and other solid materials and not in the obnoxious soluble form. Excessive iron and manganese in the impoundment would not be a problem in finished water supplies if the potential problem is recognized in the design of water treatment plants. Furthermore, the selective withdrawal capability of the proposed project would enable project operation to minimize iron and manganese concentrations in water supply withdrawals and downstream releases.

Mercury. Average mercury concentrations based on eight samples collected by the USGS near Arcadia exceeded the EPA's proposed criteria for the protection of freshwater aquatic life. However, the average Deep Fork River concentration was less than the EPA's recommended level for public water supply.

Prior to initiation of this study, the only sampling for mercury other than by the USGS was conducted by the Oklahoma Department of Public Health. Sampling conducted from below Arcadia to above Belle Isle Lake in the Arcadia Lake watershed revealed no detectable mercury concentrations; however, the detection limit of the analytical procedure used was greater than recommended limits.

Because mercury was found in concentrations exceeding some criteria and because of the few number of observations available, additional

sampling was conducted by both OSU and the Oklahoma Department of Public Health in the Deep Fork River near Arcadia and from the final effluent of the Northside STP. This additional sampling provided 55 estimates of mercury concentration in the proposed Arcadia Lake watershed. Significantly, no mercury was detected in the Deep Fork River near Arcadia. However, mercury was detected in the STP effluent on two occasions.

Storm water runoff sampling for mercury in the upper Deep Fork River above Belle Isle Lake was conducted by Association of Central Oklahoma Governments (ACOG) during October 1976. The average mercury concentration of the six samples collected during the study was less than recommended water supply criteria, but each sample value exceeded recommended limits for the protection of freshwater aquatic life.

A total of 79 analyses of total mercury were performed between 1971 and 1976. These data indicate that mercury has a low probability of degrading water supply because the mean mercury concentration computed over all samples collected near Arcadia is 10 times lower than the public water supply criterion. It is further anticipated that mercury concentrations in the proposed impoundment would decrease relative to input in much the same way that trace metal concentrations in surrounding impoundments are less than their respective input concentrations.

However, these data do not provide a basis for a conclusive evaluation of the possible adverse effects on freshwater aquatic life. Some of the reported mercury concentrations exceed the proposed criterion for protection of aquatic life. The seriousness of this potential problem could not be evaluated in a quantitative manner with the available data base because the majority of the samples had mercury concentrations less than the analytical detection limit, but the analytical detection limit was greater than the proposed criterion.

To provide a conservative approach of evaluating the potential for adverse effects of mercury on aquatic life in Arcadia Lake, representatives from the Dallas Regional Office of the EPA recommended that fish be collected from the Deep Fork River near the proposed damsite and analyzed for mercury content. The results of the analysis could directly determine the suitability of the fish as a food source by comparing body burden concentrations to FDA limits and determine the existence

of possible adverse environmental effects of mercury contamination by comparison to EPA's criteria. The EPA has published a maximum body burden concentration for mercury in fish tissue that is equal to the FDA limit. The rationale of the criterion published by the EPA is that maintenance of fish tissue concentrations below this level is sufficient to ensure the protection of freshwater aquatic life from excessive mercury. The study recommended by the EPA was expanded to include lead and all chlorinated pesticides that were considered as possible problem constituents in the proposed impoundment. North Texas State University, Denton, Texas, was selected to perform the analysis following a search of analytical laboratories capable of the required accuracy and precision.

A collection of fish consisting of green sunfish, orange spotted sunfish, bluegill sunfish, and black bullhead was obtained by the Tulsa District by electrofishing in the Deep Fork River at the proposed impoundment site. The samples were sent to North Texas State University for analysis. Results of the analysis indicated that the mercury content of fish inhabiting the Deep Fork River near Arcadia is less than FDA and EPA limits.

The sampling program for mercury in water, sediment, and fish should be continued throughout the planning, construction, and operation phases of the project. Mercury analyses should be performed by equipment with a detection limit equal to or preferably below EPA criteria for aquatic life.

Lead. In a report prepared by OSU, lead concentrations in the Deep Fork River were near and sometimes exceeded the EPA criterion. Additional data collected by the Oklahoma State Department of Health and presented in the OSU report demonstrated that 12 of 15 samples collected on a particular day also exceeded the present criterion for lead. Based largely on these data, it was concluded in the OSU report that lead would be a problem in the proposed impoundment.

Examination of the USGS data collected near Arcadia revealed that the range of dissolved lead concentrations for 25 samples collected between 1969 and 1974 was less than the most stringent criterion.

There is an apparent discrepancy in the dissolved lead concentrations in the Deep Fork River as reported by OSU and those reported by the USGS.

The discrepancy appeared to have resulted from an improper choice of a sample preservation technique. The method of acidification chosen for use in the OSU studies resulted in the measurement of dissolved lead plus some fraction of the particulate lead present in each sample. Furthermore, the OSU analyses failed to measure total lead because of the omission of the digestion step.

The evidence is overwhelming that the majority of lead in natural waters is present in particulate form. Because of the nature of the environmental chemistry of lead, particulate lead would be expected to accumulate in the reservoir sediments and be completely unavailable to the water column and biological organisms under a wide range of natural environmental conditions. An examination of USGS water-quality data from the Deep Fork River reveals that only 1.8 percent of the total lead present (on the average) is in the dissolved form.

The fact that total lead concentrations exceeded the public water supply standard suggests the possibility of a potential water-quality problem. However, the potential effects of lead in the Deep Fork River can best be assessed by comparing dissolved lead concentrations with the applicable criteria. The rationale for this assumption is that the criteria for lead are based on studies of effects of dissolved lead and the chemistry of lead precludes the conversion of significant amounts of lead from the particulate to dissolved form under natural conditions. Consequently, based on sampling of dissolved species of lead near the proposed impoundment site and the present knowledge of the water chemistry of lead, this element would not be expected to cause water-quality problems in the impoundment.

Pesticides and PCB's

Comparison of the 1976 EPA criteria with all pesticides and PCB's measured in the Deep Fork River near Arcadia revealed that lindane, chlordane, DDT, dieldrin, heptachlor, aldrin, and PCB's exceeded the recommended limits for the protection of freshwater aquatic life.

Because of the persistence, bioaccumulative properties, and carcinogenic potential of chlordane, DDT, dieldrin, heptachlor, and aldrin, the EPA did not establish numerical limits for these pesticides for water supply but recommended minimum human exposure to these

constituents. Significantly the EPA has suspended the production or restricted the use of each of these pesticides, which should result in a gradual decrease in concentrations in the environment. However, each of these pesticides was detected at least once in the Deep Fork River near Arcadia.

Data reported by the Oklahoma Departments of Agriculture and Pollution Control suggest that pesticide contamination is restricted to the upper Deep Fork River or that residues are either not transported downstream or they are rapidly degraded. Monthly sediment and water samples collected from the Deep Fork River near Beggs, Oklahoma, had no detectable pesticide residues

Pesticides, PCB's and freshwater aquatic life. The recommended limits for concentrations of most pesticides in the water columns for the protection of freshwater aquatic life are less than the detection limit of the analytical procedures used. The EPA recognized this inconsistency in their proposed critera, but provided little guidance in the interpretation of comparisons of limits to average observed concentrations. One particular problem is that the occurrence of a single detectable concentration greatly inflates the average relative to the criterion.

DDT. Thirty percent of 64 samples analyzed for DDT exceeded the EPA-recommended limit for the protection of freshwater aquatic life. DDT concentrations generally decreased over the study period but increased during the spring of 1974 to prior levels. The spring of 1974 was exceptionally wet, and most contaminants normally found associated with particulate materials exhibited peaks during this period.

The DDT degradation products, DDD and DDE, were detected once and twice, respectively, in the Deep Fork River. Neither DDD nor DDE were detected in bottom deposits of the Deep Fork River near Arcadia.

Almost all uses of DDT were canceled in March 1971. The effect of this action should be a sharp reduction of DDT additions to the watershed.

Aldrin and dieldrin. The 1976 EPA criteria specify that criteria for aldrin and dieldrin be based on the sum of the two pesticides. This recommendation was motivated by the observation that aldrin is metabolically converted to dieldrin by aquatic organisms.

Aldrin was rarely detected in the Deep Fork River and was not detected in the stream bottom sediments near Arcadia. However, dieldrin was consistently and uniformly detected in water at concentrations 10 times the recommended limit for the protection of freshwater aquatic life.

The EPA has recently suspended the major uses of aldrin and dieldrin. The expected effect of the suspension is restriction of use to structural application by licensed exterminators with subsequent declines in instream concentrations in the Deep Fork River.

Chlordane. Fifty percent of the chlordane samples exceeded the EPA-recommended limit for the protection of freshwater aquatic life. Chlordane concentrations generally decreased during the study period, but a transient peak occurred during the spring of 1974. Chlordane concentrations were consistently detected in the bottom deposits of the Deep Fork River near Arcadia.

The EPA has cancelled many of the major uses of chlordane. The expected effect of the cancellations is a reduction of chlordane additions to the watershed.

Heptachlor and heptachlor epoxide. Sixty-three measurements of heptachlor and 64 measurements of its degradation product heptachlor epoxide were made in the Deep Fork River near Arcadia between September 1969 and December 1974. Only samples collected on 22 May 1974 had detectable concentrations. No heptachlor epoxide was detected in water samples. Neither heptachlor or heptachlor epoxide were detected in Deep Fork River sediments near Arcadia.

The ACOG conducted storm water runoff sampling for pesticides in the upper Deep Fork River above Belle Isle Lake. The sampling provided two estimates of heptachlor concentrations and one estimate of heptachlor epoxide. Although heptachlor and heptachlor epoxide were detected, the reported concentrations were less than recommended EPA limits for the protection of freshwater aquatic life.

Significantly, the EPA suspended the production and use of heptachlor in July 1975, which should result in a decrease in concentrations in the environment.

Lindane. Thirty-nine percent of 64 lindane samples exceeded the recommended EPA criterion for the protection of freshwater aquatic life.

However, lindane concentrations decreased throughout the study period to levels less than the criterion. No lindane was detected in Deep Fork River sediments near Arcadia. A continuation of the pattern of decreasing concentrations should reduce concern for lindane in the Deep Fork River.

PCB's. A total of 28 samples were analyzed for PCB content between 1969 and 1975. Only one sample, collected on 24 August 1974, had a detectable PCB's content. No PCB's were detected in the sediments of the Deep Fork River near Arcadia. Because of the rare occurrence of PCB's in the Deep Fork River and the phasing out of the use of PCB's as a dielectric in electrical equipment, PCB's are not expected to exceed criteria in the proposed impoundment.

Sampling of the Northside STP revealed that the STP was a significant source of one of the PCB's, Aroclor 1254. Diversion of the STP effluent should further decrease concern for these constituents.

Fish-tissue analyses for pesticides. To provide a more definitive approach to the assessment of the magnitude of organochlorine pesticide contamination of the upper Deep Fork River, fish inhabiting the river were collected and their flesh analyzed for dieldrin, DDT, heptachlor epoxide, lindane, and chlordane.

A comparison of the population mean pesticide concentration of dieldrin, DDT, and heptachlor epoxide with FDA guidelines indicated that concentrations of dieldrin and DDT were less than the guidelines while heptachlor epoxide exceeded the guidelines. No known limits exist for lindane and chlordane.

The results of the comparison of fish-tissue concentrations of dieldrin and DDT with the FDA guidelines were to be expected since pesticide analyses of fish collected from surrounding impoundments indicated chlorinated pesticide residues 10 to 500 times less than the FDA guidelines. However, the heptachlor epoxide results seemed paradoxical since heptachlor was only detected once and heptachlor epoxide was not detected in Deep Fork River water samples. Neither pesticide was detected in sediment samples.

The gas chromatographic analyses of the fish tissue are considered inconclusive with respect to heptachlor. Such analyses for pesticides provide a screening methodology that indicates possible

pesticide contamination when eluted peaks from samples have similar retention times to known pesticide standards. The lack of eluted peaks with retention times equal to that of known pesticide standards does conclusively indicate pesticide absence or concentrations less than detection. However, if detectable peaks are eluted with retention times equal to that of known pesticide standards, confirmation of the identity of the contaminant requires additional analysis such as mass spectrometry. The only conclusion that can be made about heptachlor in the fish tissue is that heptachlor epoxide or other chemical compounds with a similar retention time was detected in the tissues of fish collected in the Deep Fork River.

The rare occurrence of heptachlor in the Deep Fork River, the failure to detect heptachlor epoxide in Deep Fork water samples, the fact that the EPA has banned the distribution and use of the pesticide, and the observation that heptachlor strongly absorbs to settling particulates suggest that heptachlor and its degradation products are not expected to exceed criteria in the water column of the proposed impoundment. Significantly, no heptachlor or heptachlor epoxide were detected in Deep Fork River sediments.

However, because of the measurement of heptachlor epoxide or other chemical compounds with a similar retention time in significant concentrations in the fish, it is recommended that additional water, sediment, and fish samples be analyzed. If heptachlor or heptachlor epoxide were again detected in significant concentrations, confirmatory analysis by mass spectrometry should be conducted.

The fish species collected from the Deep Fork River and analyzed for pesticides feed predominantly on insects, other fish, and crustaceans. Thus these fish are positioned in a food chain whose origin is in the sediments and associated particulate materials. Since pesticides and related compounds generally exhibit sorption tendencies with particulates, the evidence suggests that concentrations of pesticides in fish in the proposed impoundment would be less than observed in fish from the Deep Fork River.

Chlorinated hydrocarbon pesticides and public water supply. The EPA recommends that human exposure to chlordane, DDT, dieldrin, heptachlor,

and aldrin be minimized. An extremely conservative interpretation of EPA's recommendation is that concentrations of these pesticides should be less than detection limits in public raw water supplies. However, each of these pesticides was detected at least once in the Deep Fork River near Arcadia.

Significantly, the EPA has suspended the production and use or severely restricted the use of each of these pesticides. Permissible uses of pesticides that were not totally banned include termite control, nursery root dips, and other uses in which washoff and subsequent contamination of waterways are minimized. The EPA suspensions and restrictions should result in a gradual decrease in concentrations in the environment.

One additional chlorinated hydrocarbon pesticide, lindane, was detected in the Deep Fork River near Arcadia. However, average lindane concentration was 50 times lower than EPA recommended levels for public water supplies. At present lindane is readily available and its usage in the Arcadia Lake watershed is not controlled. However, average yearly concentrations of lindane in the Deep Fork River have uniformly declined over the study period, which should lessen concern for this pesticide.

The pattern of occurrence, as well as the magnitude of contamination from restricted pesticide residuals in the Arcadia Lake watershed, depends upon the rates of pesticide degradation and land-use activity. Reported degradation times defined as the time required for 75-percent degradation in soils varies from 2 yr for heptachlor and aldrin to 5 yr for chlordane. Land-use activity, especially construction, substantially increases the washoff of particulates with adsorbed contaminants from the watershed.

If chlordane, the most persistent and most frequently occurring pesticide in the Deep Fork River, were totally banned, residual concentrations might be detected in sediment for approximately a decade. However, sediment concentrations provide a poor indication of possible adverse effects. Adverse ecological effects are dependent upon the absorption or ingestion of the pesticide by aquatic organisms, while concentrations in raw water supplies are dependent upon the sedimentation characteristics of the impoundment.

Pesticides are not expected to violate water-supply criteria in the proposed impoundment because sorption and precipitation would reduce

concentrations significantly and restricted use of most of the persistent pesticides has been implemented or proposed by the EPA.

Other water-quality parameters

Phenols, total dissolved solids, and coliform bacteria were identified as possible water-quality problems in the proposed impoundment. These parameters cannot be conveniently classified into the generic classes of nutrients, metals, or pesticides and thus are discussed separately.

Phenols. The average of phenol concentrations measured over the period 1969-1974 exceeded the most stringent criterion that was established based on taste and odor considerations. Phenol concentrations in Arcadia Lake are expected to be much lower than measured instream concentrations. First, the Northside STP was found to be a significant source of phenol, and diversion of the effluent would decrease loadings 40 percent. Secondly, phenol is a very labile compound in natural waters with reported persistence times varying between two to eight days. Based upon these observations, phenol is not expected to be a problem in the proposed impoundment.

Total dissolved solids. The expected total dissolved solids concentration in the proposed impoundment would exceed recommended levels but would be less than present Oklahoma standards. Oklahoma's standards explicitly provide an allowance for high natural background levels for this constituent. The most stringent criterion for public water supplies was established primarily because of objectionable physiological effects, mineral taste, and economics of treatment when dissolved solid concentrations greatly exceed this value. Toxicological effects would not develop in the impoundment due to total dissolved solids.

Coliform bacteria. Two total coliform bacteria and three fecal coliform sample values measured near Arcadia by the USGS were available prior to the initiation of this study. Although the measured values were reasonable for urban drainage, additional sampling was initiated by the Tulsa District to characterize the temporal variation in coliform concentrations. The Oklahoma State Health Department collected duplicate samples of water from the Deep Fork River near Arcadia and the final effluent of the Northside STP and analyzed them for both total and fecal coliform bacteria. The sampling was conducted weekly from 29 March 1976 through 1 June 1976.

Total coliform and fecal coliform bacterial numbers measured in the final effluent of the Northside STP were about 17 times higher than measured in the Deep Fork River near Arcadia. These data suggest that the sewage treatment plant is a significant source of bacteria. However, coliform numbers measured near Arcadia are of a similar magnitude to those measured in urban runoff for Tulsa, Oklahoma.

Coliform bacteria rapidly die when isolated from their source. Based on mathematical modeling results and observations on the coliform distribution in Lakes Eufaula and Thunderbird, it is anticipated that coliform concentrations in the upper reaches of the reservoir would exceed primary contact recreational standards, while waters in the lower half of the reservoir near the dam would be suitable for primary body contact recreation with the possible exception of short periods following major storm events. Selection of recreational areas should reflect the expected distribution of coliform bacteria, and routine bacteriological monitoring should be conducted to detect bacterial contamination of recreational areas.

Conclusions and Recommendations

Conclusions concerning impoundment water quality based upon this study are as follows:

a. The proposed Arcadia Lake would be thermally stratified intermittently during the summer months. No permanent or stable temperature stratification is expected.

b. During the summer and early fall months, release temperatures may be up to 12°F warmer than natural downstream temperature.

c. In general, dissolved oxygen concentrations in the reservoir and in downstream release will support aquatic life. Bottom waters of the reservoir may become devoid of dissolved oxygen during periods of intermittent stratification.

d. The well-oxygenated waters should reduce the level of iron and manganese concentrations near the dam. However, manganese is expected to violate drinking water standards the majority of the time while iron may occasionally exceed standards in the headwater area of the impoundment or in the bottom waters near the dam during periods of stable stratification. Total dissolved solids are

expected to exceed standards throughout the impoundment. The standards for iron, manganese, and total dissolved solids are based on aesthetic rather than toxicological considerations and will not result in major water supply problems if considered in treatment plant design.

e. Pesticides and heavy metals are not anticipated to vitiate project purposes. Fecal coliform standards for primary contact recreation were not violated near the dam at any time during the simulations. Coliforms are expected to exceed standards in the headwater area of the impoundment and may be high in the upper third of the impoundment following most storm events; the standards may be exceeded throughout the reservoir following major storm events.

f. Two or three major algae blooms may be expected each year depending upon hydrometeorological conditions. It is expected these blooms will be similar in magnitude to those occurring in Lakes Keystone, Thunderbird, and Carl Blackwell and may cause taste and odor problems in the water supply. These potential problems can be provided for in treatment plant design.

g. Water-quality requirements for project purposes of municipal and industrial water supply and for general recreation are expected to be met by the predicted water quality for the proposed Arcadia Lake.

The following recommendations are made:

a. The sampling program for coliform bacteria, pesticides, and heavy metals - particularly mercury - should be continued throughout the planning, construction, and operation phases of the project. Mercury analyses should be performed by equipment with a detection limit equal to or preferably below EPA criteria for aquatic life.

b. Prior to impoundment, additional samples of fish should be collected from the Deep Fork River near the proposed damsite and analyzed for body burdens of mercury and the pesticides heptachlor and heptachlor epoxide. If gas chromatography indicates heptachlor or heptachlor epoxide to be present in significant concentrations, its identity should be verified by mass spectrometry. If presence is confirmed, a more thorough evaluation of its source and potential fate and consequences in the reservoir should be made prior to construction if the results of the recommended sampling program indicate a potentially significant problem.

c. Recreation sites should be located in the lower half of the impoundment to minimize the potential for coliform bacteria interfering with body contact recreation. The lower half represents a conservative value since most storm events are expected to impact only the upper third

of the proposed impoundment with respect to coliforms violating body contact recreation standards. Routine bacteriological monitoring should be conducted to detect bacterial contamination of recreation areas.

d. The selective withdrawal capability should be maintained in the structure to permit the withdrawal of water supply from three depths within the impoundment. These three ports should be located to permit the withdrawal of surface, mid-depth, and bottom waters. The bottom port is in addition to the floodgates. During algae blooms, water may be withdrawn from the bottom to ameliorate taste and odor problems. During stratification periods, surface or mid-depth waters may be withdrawn to minimize manganese and iron concentrations.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Hall, Ross W

Summary report, Arcadia Lake water-quality study, by R. W. Hall, Jr., R. L. Eley, and D. L. Robey. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.

27 p. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper Y-77-3)

Prepared for U. S. Army Engineer District, Tulsa, Tulsa, Okla.

Bibliographical footnotes.

1. Arcadia Lake, Okla. 2. Mathematical models. 3. Nutrients. 4. Water quality. I. Eley, Rex L., joint author. II. Robey, Donald L., joint author. III. U. S. Army Engineer District, Tulsa. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper Y-77-3)

TA7.W34m no.Y-77-3